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A METAL FOR STEAM TURBINES WITH HIGH AND SUPERCRITICAL STEAM PARAMETERS

E. S. Ginzburg

The creation of steam turbines with high steam parameters and large per-unit powers was the result of advances in domestic metallurgy and power-machinery construction which were related to finding and mastering the production of new heat-resistant steels of the pearlitic and austenitic varieties, to the use of new technological processes, chiefly the welding of large thick-walled machine parts, and to the development of new designs which facilitate the operating conditions of the metal.

A complex of the most diverse requirements which stem from the operating conditions of the individual parts, is imposed upon a turbine metal; these requirements are continually being intensfied with the increase in operational steam parameters and per-unit powers. Rotor blades, seamless-forged rotors, discs, and fastenings are the turbine elements under the greatest load. While the last-stage blade in a VK-100 turbine is under a centrifugal force of 42 metric tons, the last-stage blade in a PVK-150 turbine is under a centrifugal force of 85 metric tons.

A metal for turbine parts should possess a high yield point at room and operating temperatures, great heat resistance — creep resistance and relaxation stability, high fatigue strength, low sensitivity to stress concentration, as well as corrosion and erosion stability.

Obtaining large forged pieces and castings with the good properties mentioned above is the most serious problem in present-day metallurgy. Suffice it to say that domestic industry is capable of preparing rotor forgings of austenitic steel from ingots weighing no more than 13 metric tons which by no means satisfies current requirements. The solution of this problem involves the adoption of the method of melting and casting metal in a vacuum, a more widespread introduction of the processes of modifying liquid steel, and a number of other methods for improving the quality of metal in the course of its production.

However, the efforts of metallurgists alone are not sufficient to solve the extremely complex problems involved in providing metal for turbine builders and ensuring the necessary operational reliability of the units. Turbine builders are faced with urgent problems regarding the development and use of cooling and heat-screening systems, which would allow them to use pearlitic steel instead of austenitic in a number of cases. The use of welded austenitic and pearlitic steel rotors will allow us to confine the use of small austenitic forgings to the high-temperature zone. The maximum elimination of flange couplings and their replacement by special threaded couplings (telescopic movable or welded) and the heating of flanges and fastenings will decrease the temperature stresses in the metal of turbine casings and fastenings during stopping and starting; many turbine factories and research institutes are doing extensive work in this direction.

Metal for the Steam Turbines SVK-150-1 and SVR-50-3

The first SVK-150-1 steam turbine with a power of 150 Mw and a speed of 3000 rpm was designed for steam parameters of 170 atm abs and 550/520°C [75]. At that time (1952) this turbine was the most powerful in Europe. In order to construct it, it was necessary to assimilate into production forge pieces and castings of new highly heat-resistant brands of steel, among them austenitic steels, which find relatively wide application in this machine. Experience gained from the operation of two SVK-150-1 turbines over a long period of time has demonstrated the possibility of a further increase in the temperature of the live steam to 570°-580°C and the temperature of intermediate reheating to 530-535°C.

As for the selection of materials and the design decisions, the grades of steel used and the design of the high-pressure cylinder, in which the highest-temperature steam operates, occur for the first time in these turbines.

In the first machines the chests of the automatic shut off valves weighing 7000 kg and the steam chests weighing 700-900 kg were constructed from castings of complexly alloyed brand LA-1 austenitic steel (0.10C + 15Cr + 15Ni + 2Mo + 1W + 3Co + 0.2Ti). However, the construction of large shaped castings of this steel presented extremely great difficulties. A considerable number of defects were observed on the steam-chest castings and were repeatedly cut out and welded up over a long period of time. The weight of the metal fused on certain steam chests reached 20-25% of the weight of the entire chest. Since the reparation of the defective chests was an extremely tedious operation and there was no assurance that the welded chests would be sufficiently reliable in operation, the factory gave up casting and

switched over to constructing the steam chests and automatic shutoff-valve chests by the method of welding separate forgings of brand EI-405 austenitic steel (0.1C + 16Cr + 13Ni + 2Mo + 1Nb). The depth of the welded seam on the automatic shutoff-valve chest was 140 mm. The welding of thin-walled structures did not create any special difficulties, but the welded joints with these massive seams, the execution of which gives rise to great stresses, had cracks. As a result of selecting the appropriate composition of fused-on metal and perfecting the various technological factors, there were developed grades of electrodes and a welding and heat-treatment technique which enabled us to obtain massive seams of good quality. This work was carried on by the Leningrad Metalworking Plant, in conjunction with the Central Scientific Research Institute of Technology and Machine Building and the Central Scientific Research Institute for Boilers and Turbines. Welding of grade LA-1 steel was done with TsT-7 and TsT-13 electrodes, while EI-405 steel was welded with TsT-7 and KTI-5 electrodes. In welding LA-1 and EI-405 austenitic steels the parts being welded were allowed to heat to no higher than 100°C near the seam. The welding was done on a short arc using electrodes 4 and 5 mm in diameter at currents of 110-130 and 140-160 amps, respectively. Each seam roller was subjected to peening with a pneumatic hammer having a head with a radius of curvature of 2-3 mm.

A significant increase in the volume of the welding work proved more profitable than repeated reparation of casting defects.

The construction of an LA-1 austenitic steel all-cast inner housing of complex configuration was declined by the factory. Such large (5,850 kg) all-cast parts are inaccessible to inspection and control, as well as to the carrying out of repair work. Hence the

inner cylinder was constructed by means of welding seperate castings which were of less weight and of sufficiently simple shape. The automatic shutoff-valve chest and side chests of the SVK-150 turbine in the cast and welded-forged version are shown in Fig. 1-3, while the welded-cast inner cylinder is shown in Fig. 4 [76].

The outer casing of the cylinder was prepared from a casting of chromomolybdeno-vanadium pearlitic steel brand 20 KhMF-L (0.2C + 1Cr + + 0.6Mo + 0.25V). In the most recent productions of the SVK-150-1 machines the inner casing of the cylinder was also made out of 20KhMF-L pearlitic steel.

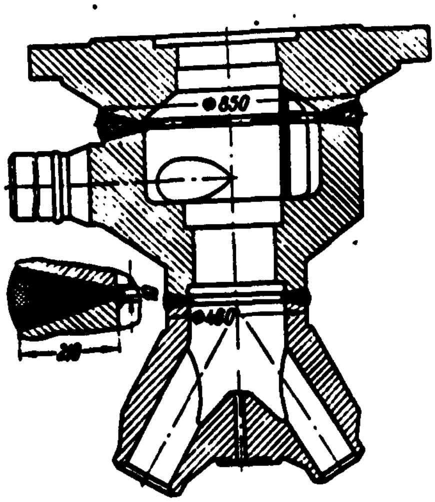

Fig. 1. Automatic shutoff-valve chest of the SVK-150 turbine in the welded version consisting of forged parts.

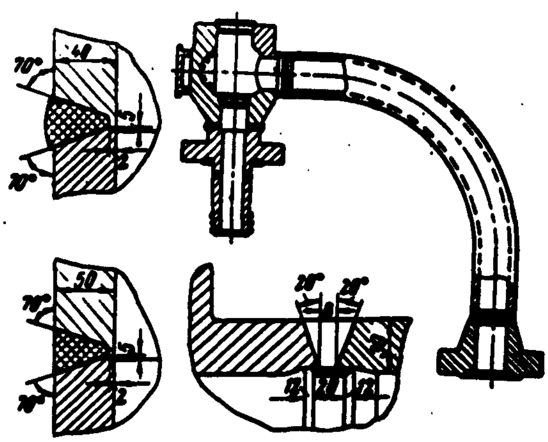

Fig. 2. Upper steam chest of the SVK-150 turbine.

The seamless-forged rotor 5,656 mm in length with a maximum body diameter of 870 mm was made out of R2 chromomolybdenovanadium steel R2 (0.25C + 1.5Cr + 0.7Mo + 0.25V). The rotor billets were delivered to the plant in coarse-processed form after final heat treatment. Testing of the quality of the metal of the rotors was on an individual basis and was conducted on specimens, which had been cut out of special

allowances on the forging.

The buckets of the rate wheel as well as the rotor blades and guide vanes of the second through fourth pressure stages were made of EI-405 steel.

EI-257 austenitic steel (0.1C + 14Cr + 14Ni + 2.5W + 0.5Mo), was used for the steam pipes in the first machines, while 1Kh18N12T steel was used in subsequent ones. The armature casting was made of La-3 austenitic steel (0.15C + 14Cr + 14Ni + 1.5W + 2Mo + 0.4Nb + 0.2Ti + + 0.5V) while the fastenings were made of EI-572 steel (0.3C + 18Cr + + 9Ni + 1.2Mo + 0.3Nb + 0.3Ti + 1.3W).

It should be noted that all steels used in the SVK-150-1 turbine were recently developed, with the exception of EI-405 and EI-257, on which a little experience had been acquired in application to turbine construction (EI-405) and on an experimental boiler at 300 atm (gage) and 600°C at the Heat and Electric Power Plant of the All-Union Heat Engineering Institute (EI-257).

The special design feature of the SVK-150-1 turbine is the coupling of austenitic and pearlitic steel parts: an austenitic valve chest with a pearlitic outer cylinder and an austenitic nozzle chest with a pearlitic inner cylinder. A diagram of this construction is shown in Fig. 5 and consists of the following: in the cylindrical bore of the pearlitic (outer) cylinder austenitic sleeve pipes are inserted; thus the austenitic bolts tighten only a small segment the height of the pearlitic outer cylinder, and the difference in the elongation of the bolts and that of the flange-coupling elements tightened by them is insignificant. The same scheme was adopted in the coupling of the nozzle chests and the inner pearlitic cylinder. The design of the steam-supply pipe was executed in the form of a movable coupling

between the connecting pipe of the valve chest and the mouth of the nozzle chest. The connecting pipe of the valve chest enters the mouth of the nozzle chest. The sealing between them is effected with piston rings.

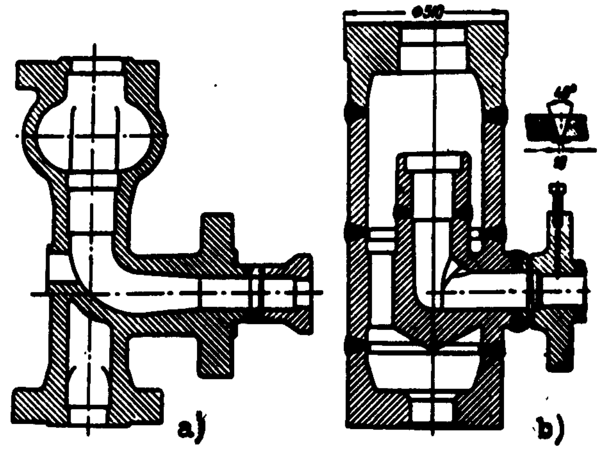

Fig. 3. Side steam chest of the SVK-150 turbine. a) cast version; b) welded-forged version.

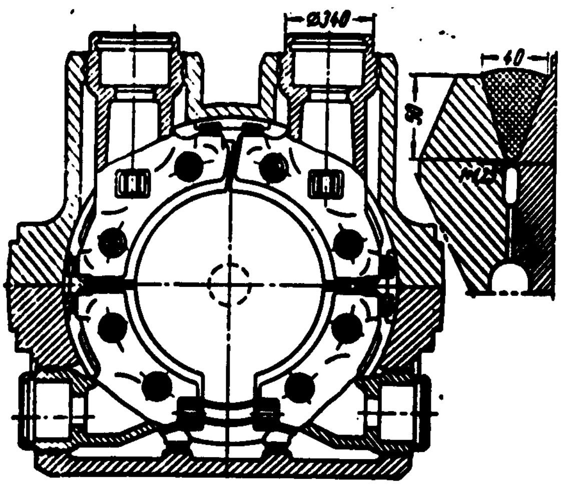

Fig. 4. Welded-cast inner cylinder of SVK-150 turbine.

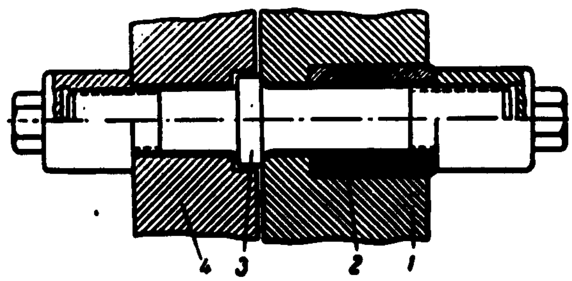

Fig. 5. Construction of flange coupling of austenitic valve chest and pearlitic outer cylinder. 1) flange of outer cylinder; 2) austenitic sleeve pipe; 3) austenitic stud bolt; 4) flange of steam chest.

From the brief description of the special features of the production of the SVK-150-1 turbine and of the materials used it is apparent that its creation and assimilation required solutions to a number of complex problems of a metallurgical and technological nature.

The construction of the superimposed turbine SVR-50-3 by the Leningrad Metalworking Plant with a power of 50 Mw with steam parameters of 200 atm abs and 580°C has much in common with the SVK-150-1 turbine and was planned, taking into account the experience gained in the production and operation of this latter turbine [77]. The automatic shutoff-valve chests and the steam chests were made out of welded forgings of EI-405 austenitic steel. The inner cylinder was cast from 20 KhMF-L perlitic steel. The cast outer cylinder was made out of the same steel. The coupling of austenitic and pearlitic steel parts was accomplished according to the same principle as in the SVK-150-1 turbine.

The seamless-forged rotor was made of R2 pearlitic steel; the rotor blades and guide vanes were made of stainless chrome steel brand 15Kh11MF (0.15C + 11Cr + 0.5Mo + 0.25V). The diaphragms of the first five stages were forged out of chromomolybdenovanadium steel brand 12 KhMF, while the remaining ones were forged out of chromomolybdenum steel brand 15KhMA. The material of the bolts of the horizontal joint of the inner cylinder is EI-723 steel (0.25C + 2.3Cr + 1.0Mo + 0.4V), while that of the outer cylinder is EI-10 steel (0.25C + 1.6Cr + + 0.3Mo + 0.2V).

The steam pipes were built of austenitic steel brand 1Kh18N12T.

The Metal of Steam Turbines with Steam Parameters of 130 atm abs and 565°/565°C and 240 atm abs and 585°/565°C

The PVK-150 turbine (produced by the Kharkov Turbogenerator Plant) with a power of 150 Mw and the PVK-200 (produced by the

Leningrad Metalworking Plant) with a power of 200 Mw and steam parameters of 130 atm abs and 565/565°C were built exclusively of pearlitic steels [78]. K-300-240 turbines with a power of 300 Mw and steam parameters of 240 atm abs and 580°C, in which only pearlitic steels are being used, are in production.

The basic special feature of the PVK-150 turbine is its two-cylinde construction. This is the first single-shaft two-cylinder turbine with such high power at 3000 rpm to be built either here or abroad. The two-cylinder construction of the PVK-150 has become possible, owing to the fact that the rotor of the low-pressure cylinder was welded out of forged discs of 34KhM steel and also because of the use of blades in the last stage with an active length of 780 mm with the mean diameter of the stage being 2,125 mm. This is the longest blade being built for 3000 rpm turbines.

In the forward portion, the high-pressure cylinder of the PVK-150 is double-walled. The cutoff valve casing, the steam and nozzle chests, and the inner-cylinder casing were prepared from casts of pearlitic steel grade 15Kh1M1F-L (0.18C + 1.5Cr + 1Mo + 0.3V). The casts, which weighed 4-6 metric tons and had a wall thickness of from 50 to 300 mm were produced by the Lenin Neva Plant. The casts were subjected to heat treatment according to the following regime: 1) homogenization at 1,050°C followed by cooling in air to 500°C; 2) normalization at 1000°C followed by accelerated cooling with a compressed-air blast to 500° and then in still air; and 3) tempering at 710-740°C and oven cooling to 200°C. The defects in the casting were welded up after heating to 300°C. After the welding tempering was carried out at 670-680°C. In order to detect cracks, the castings were subjected to a kerosene test or to etching at all places of transition with a

15% aqueous solution of ammonium persulfate and a 10% aqueous solution of nitric acid. A study of the mechanical properties of a full-size casting weighing 6 metric tons, which was carried out at the laboratory of the Kharkov Turbogenerator Plant showed that the yield point of the metal $\sigma_T = 36 - 65$ kg mm², the tensile strength $\sigma_B = 57 - 78$ kg mm², and the impact strength had extremely high and uniform values. The stress-rupture strength for 100 thousand hours of specimens cut out of the casting at a testing temperature of 570°C was 9 - 10 kg mm² (for specimens with $\sigma_T = 35 - 45$ kg mm²). The outer casing of the high-pressure cylinder was made of a casting of chromomolybdenovanadium steel brand 20KhMFL. Series castings of this brand of steel weighing more than 25 metric tons are in production. The rotor of the high-pressure cylinder was forged in one piece out of EI-415 steel (0.2C + + 3Cr + 0.5Mo + 0.4W + 0.7V). The steel is melted in acid open-hearth furnaces and poured out into ingots weighing up to 50 metric tons. The ingots are forged on a 10-metric-ton press. The weight of the forging was 25 metric tons before stripping and 17 metric tons after stripping. The rotor forgings underwent heat treatment according to the following regime:

1. After forging was completed, isothermic annealing was carried out at 650°C, furnace cooling to 300-350°C; heating to 650°C, 48-hour holding; further heating to 920—950°C with a 32-hour holding, furnace cooling to 300—350°C, 30-hour holding; heating to 660—680°C, 84-hour holding, furnace cooling to 100°C.

2. After stripping: a) normalization at 1,050—1,100°C, cooling in air; b) oil quenching at 990-1,010°C; c) tempering at 660—680°C, 28-hour holding, furnace cooling.

The full-size rotor forging weighing 17 metric tons with a body

diameter of 860 mm, which had been prepared from a 47-metric-ton ingot, was investigated by the laboratory of the Kharkov Turbogenerator Plant. The investigation showed the following mechanical properties for the metal along the length of the forging at 20°C: yield points $\sigma_T = 60 - 70$ kg/mm², tensile strength $\sigma_B = 70 - 80$ kg/mm², relative elongation $\delta_{10} = 14.5 - 17.5\%$, relative contraction $\psi = 58 - 66\%$, impact strength $a_k = 9 - 19$ kg · m/cm². A study of the mechanical properties over the cross section of the forging, going from the periphery to the opening, showed a dispersion of the impact-strength values from 8.2 to 3.3 kg · m/cm². The strength and plasticity characteristics had sufficiently uniform values. Tests on the fatigue strength of smooth and notched specimens cut out of places in the journal bearings of the rotor at a temperature of 20°C and a test base of 10 million cycles showed the fatigue limit for bending with rotation to be $_{\sigma-1} = 35.5$ kg/mm² (smooth specimens) and $_{\sigma-1} = 16$ kg/mm² (specimens with a circular notch 0.2 mm in radius, 60° angle, ratio of areas 1:2). The creep limit for a creep rate of $1 \cdot 10^{-5}\%$ per hour was $\sigma_c = 9$ kg/mm² at 550°C and 8 kg/mm² at 600°C. The stress-rupture strength for a period of 100 thousand hours $\sigma_{s-r} = 19$ kg/mm² at 550°C. The microstructure of the rotor metal consisted of sorbite. From the periphery towards the center there was observed an enlargement of the sorbite structure with the appearance of areas of structurally free ferrite, the number of which increased, as the distance to the forging axis decreased.

The PVK-200 turbine of the Leningrad Metalworking Factory is a three-cylinder, single-shaft turbine [79]. The high-pressure cylinder is a welded-cast construction with welded-in nozzle chests, onto which the steam chests are welded directly. The casing of the high-

pressure cylinder, the nozzle and steam chests, and the casings of the automatic shutoff-valves are made of 15Kh1M1F-L cast steel. The casing of the medium-pressure cylinder in the forward section, where the steam enters after intermediate reheating is also made of welded castings of 15Kh1M1F-L steel. The largest castings are the castings of the high-pressure cylinder. The weight of the casting of the upper half of the cylinder is 14,000 kg; and that of lower half, 17,600 kg. The welding on the high-and medium-pressure cylinders was done on TsL-27 electrodes with an over-all preheating of the welded parts to 350—400°C on the sole of the furnace. Tempering began immediately after completion of the welding. In the first castings, which were welded using local preheating, a large number of cracks were observed in the welded seams and in the zone near the seams. Subsequent experience with the welding showed that it was possible to weld using local preheating, but the cooling rate after welding must not exceed 40 — 50°C per hour.

The rotors of the high-and medium-pressure cylinders were forged in one piece and prepared from R2 steel which had been used previously at the LMF for the SVK-150 turbine. During recent years the Ural Machinery Factory has carried out a number of experimental and research projects to perfect the technology of the production of large R2 steel forgings, to improve the quality of the ingots and forgings, to eliminate the inhomogeneity previously observed in the properties, and to study the impact strength of the metal of rotor forgings. The factory mastered and incorporated the method of pouring large ingots under a vacuum. This reduced the over-all content of nonmetallic inclusions by a factor of 2-4 and, what was especially important, reduced the hydrogen content by a factor of 2-3. Ingot metal poured under vacuum

has a more compact macrostructure and a considerably lower axial friability. Large forgings of vacuum-processed steel have better plasticity characteristics in comparison with the corresponding characteristics of ordinary ingots. The second major step taken was the perfection of a process of heat treatment for large forgings which is carried out according to the following regime: a double normalization at 980-1000°C and 960-980°C, cooling in a compressed-air stream. Tempering at 680-690°C. Before 1958 the second normalization of R2 steel rotors was done in still air in a vertically suspended state. This method did not ensure that stable and uniform mechanical properties would be obtained. Cases were often noted in which decreased values were obtained for the impact strength (the impact strength had values from 10 to 1.2 kg · m/cm^2), and in some cases decreased values were obtained for the yield point. A study of this problem revealed that it was possible to ensure satisfactory and homogeneous mechanical properties on rotors of R2 steel if the prescribed heating temperature was strictly observed during the second normalization and accelerated cooling. For this purpose there were designed and installed at the factory in 1958 special circular chambers with double walls with an inner diameter of 1,500 mm. Air from blowers with an individual output of 30,000 m^3/hour was fed into the chambers in a tangential direction through specially constructed slits. The accelerated cooling in the normalization process allowed the tempering temperature to be raised from 680°-710°C, the same final mechanical properties being obtained. This was favorably reflected in the plasticity characteristics along the length of the rotor, which had been caused by the different hydrogen contents at the top and the bottom of the ingot.

At the present time turbine factories are obtaining large rotor

forgings (ingot weight up to 70 metric tons) of high quality with good uniform properties in accordance with the requirements of TU-1284.

The requirements pertaining to the mechanical properties and billets for rotors of R2 steel are as follows:

Direction of out of sspecimens	σ_B, kg/mm²	σ_T, kg/mm²	δ, %	ψ, %	a_k, kg.m/cm²	Cold bend test around mandrel 40 mm in diameter through an angle.
Longitudinal	≥65	≥45	≥16	≥40	≥5	180°
Tangential	≥65	45—72	≥13	≥35	≥4	150°

The value guaranteed for the stress-rupture strength for 100,000 hours is 14 kg/mm² at 550°C; while the creep limit σ_p for a 1% deformation in 100,000 hours at the same temperature equals 9 kg/mm². The rotor forgings were subjected to individual quality tests. The majority of the methods of rotor control have been used in turbine production for many years and are generally known. The only exception is ultrasonic quality control, to which 100% of the forgings are presently subjected.

Ultrasonic control is carried out with the aid of the UZD-7N defectoscope produced by the Central Scientific Research Institute of Technology and Machine Building at a frequency of 2.5 megacycles with cylindrical probes. The sensitivity of the instrument is controlled with special calibrating devices with a bore 2 mm in diameter with a flat bottom at a depth of 380 mm below the sounding surface.

In the K-300-240 turbines, which have a unit power of 300 Mw and steam parameters of 240 atm abs and 580°C new P1 and P3 pearlitic steels are used on the cast parts; EI-909 steel on the fastenings; and also stainless 12% chrome steel grade TsZh5 and Kh11L on the casting, EI-802 on the blades and rotors, and EI-993 on the fastenings.

P1 (0.16C + 1.2Cr + 1Mo + 0.3V + 1.4Co + 0.005B) and P3 (0.16C + + 2.2Cr + 1.5Mo + 0.3V + 0.12Nb) steels were developed through additional alloying of the most heat-resistant pearlitic steels of brands 12KhMF and 15Kh1M1F. P1 steel has heat-resistant properties at 580-600°C equal to the heat-resistant properties of a number of austenitic steels. The stress-rupture strength after 100,000 hours at 580°C is 18 kg/mm², while at 600°C it amounts to 14 kg/mm². The creep limit at the same temperatures is equal to 14 and 10 kg/mm², respectively.

P1 steel possesses sufficient resistance to scaling. In a steam medium at 600°C its oxidizability does not exceed 0.1 mm of wall thickness per year. Moreover, the oxides that are formed are impenetrable and plastic, and they adhere firmly to the metal surface. EI-909 steel (0.22C + 1.2Cr + 1.0Mp + 0.8V) is the most relaxation-stable pearlitic steel; at 565°C with an initial stress of 35 kg/mm² the residual stresses amount to 12 kg/mm² for 10,000 hours. For the rotors of the pilot samples of the K-300-240 turbines EI-415 steel was used by the Kharkov Plant and R2 steel by the Leningrad Plant.

The use of steam of supercritical parameters for 3000 rpm 300 Mw turbo-units poses the very important problem of the development of new materials for the blades of the final stages.

The blades of the PVK-150 turbine produced at the Kharkov Turbogenerator Plant, which are 780 mm in length with the mean diameter of the stage being 2,125 mm, are under a centrifugal force of 85 metric tons [80]. The stresses caused by this force are the limiting stresses for the stainless chrome steel brand 2Kh13 which is presently being used for these blades. In the K-300-240 turbines produced by the Kharkov Turbogenerator Plant the blades of the last stage have a length of 860 mm with the mean diameter of the stage being 2,389 mm. The

major problem in the creation of low-frequency blades for the last stages of powerful steam turbines is assuring their vibrational reliability. In the case of possible resonance oscillations the dynamic stresses arising in the blades are proportional to the static bending stresses caused by the total steam flow and inversely proportional to the damping decrement of the oscillations. Hence it is necessary to reduce to a minimum the static steam-bending stresses in the blades and to increase their damping characteristics. The most promising material for the blades of the last stages are titanium alloys, which, while they have a specific gravity only half that of stainless steels, excel them in strength properties, as well as in erosion and corrosion stability. At the present time there has been developed a whole series of industrial alloys of commercial titanium with aluminum, manganese, chromium, iron, and other elements. In a titanium alloy the aluminum concentration is usually 3-6%, while the manganese concentration may be as much as 7%.

Data on the mechanical properties of certain titanium-base alloys at room temperature are given in Table 1 [81].

TABLE 1

Mechanical Properties of Titanium Alloys

Content of alloying elements (base - titanium) %	Mechanical properties		
	Tensile strength σ_B, kg/mm²	Yield Point σ_T, kg/mm²	Relative elongation δ, %
2% Mn; 2% Al	73,5	—	15,0
4% Mn; 4% Al	96,0	91,0	10,0
3% Mn; 1,5% Al	86,1	81,9	17,0
1% Mn; 5% Al; 2,75% Cr	105,0	96,0	8,0
1% Mn; 5% Al; 1,5 Cr; 1,25% Fe	108,5	98,0	12,0

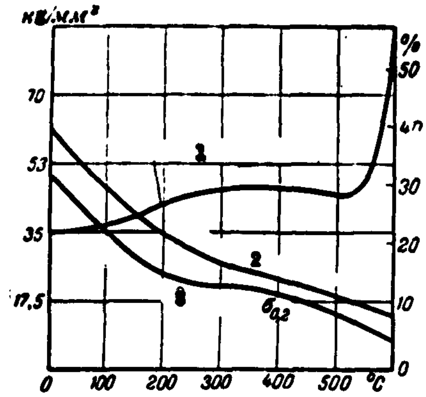

Fig. 6. Mechanical properties of commercial titanium. 1) elongation (for 50.8 mm) 2) tensile strength 3) yield point $\sigma_{0.2}$

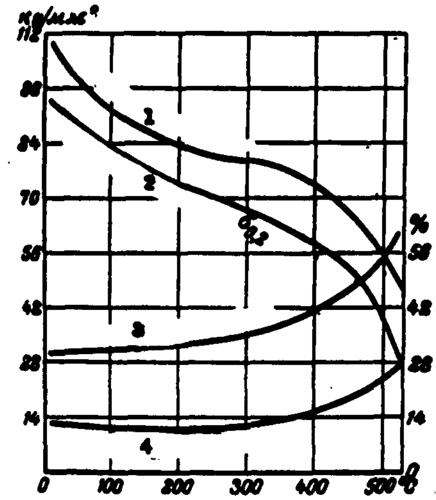

Fig. 7. Mechanical properties of an alloy of commercial titanium with 4% Al and 4% Mn. 1) tensile strength 2) yield point $\sigma_{0.2}$ 3) transverse contraction 4) elongation (for 25 mm)

Testing temperature, °C	σ_B, кг/мм²	-1, kg/mm² based on 10^7 cycles	
		Smooth specimens	Notched specimens
25	63	52	19

Prospects of Raising the Temperature Level for the Use of Pearlitic Steel

The question of heat resistance (resistance to scaling), along with the question of high-temperature strength, acquires special importance in regard to raising the temperature level for the use of pearlitic steels to 600-610°C. Hence domestic and foreign technology has set about to find new compositions of steels on a base of 12% chrome stainless steels which have high resistance to scaling for casting, large forgings, blades, fastenings, and other turbine parts.

Data on the composition properties, and use of stainless chrome steels are given in Table 2 [82]. It should be noted that additional

alloying of 12% chrome steels with molybdenum, tungsten, and vanadium, which increase the heat-resistant properties of these steels, decreases their resistance to scaling. Steels of brands 15Khl1MF and EI-802 are being used successfully for the blades and valve rods in the PVK-150, PVK-200, and K-300-240 turbines. In applying these steels to large forgings and castings it is necessary to take their tendency toward zonal and dendritic segregation into account, since this creates inhomogeneity of the structure and properties over the cross section of the forging or casting. In order to diminish the segregation phenomena, the Central Scientific Research Institute of Technology and Machine Building is modifying brand TsZh5 steel with calcium. Rotor forgings of brand EI-802 and EI-756 steel were investigated at the Kharkhov Turbogenerator Plant. An investigation of a forging weighing 10,833 kg from a 38-metric-ton ingot of EI-802 steel showed that in the heat-treated state (oil quenching at 1,050°C and tempering at 720°C) an impairment of the mechanical characteristics (strength and plasticity) was noted. The yield point has the values 50-54 kg/mm². The impact strength of tangential specimens has the values 1.2-3.5 kg · m/cm². According to the data of the Central Scientific Research Institute for Boilers and Turbines, at a testing temperature of 600°C the stress-rupture strength of this forging for 100,000 hours $\sigma_{s-r} = 7.8$ kg/mm², while the creep limit $\sigma_p = k$ kg/mm².

A 21,700 kg forging prepared from a 43-metric-ton ingot of EI-756 steel had a yield point 6-9 kg/mm² below the TUMI- 238-56 requirements. The impact strength of tangential specimens attained 2.7 kg · m/cm² at 50°C.

Research projects on these steels are being continued to find means of obtaining a more homogeneous structural state and good mechanical characteristics in large forgings and castings.

TABLE 2

Chemical Composition and High-Temperature Strength of Turbine Steels

Brand	Chemical composition, %									High-temperature strength		Use
	C	Si	Mn	Cr	Ni	Mo	V	W	Nb	[illegible]	[illegible]	
EI LA	0,12—0,19	≤0,50	0,50—1,0	10,0—11,5	0,60—1,0	0,60—0,80	0,25—0,30	—	0,15—0,25	5—6	8	Turbine casting
EI LB	0,12—0,19	≤0,50	0,50—0,1	10,5—12,0	0,60—1,0	0,60—0,80	0,25—0,30	0,80—1,1	—	4,0	8,5	The same
[illegible] (Tech)	0,10—0,17	0,17—0,40	0,60—0,80	10,5—12,5	0,90—1,0	0,60—0,80	0,20—0,35	1,7—2,2	—	5,5	9,0	"
EI MF	0,12—0,19	≤0,50	≤0,60	10,0—11,5	—	0,60—0,80	0,25—0,40	—	—	—	—	Forgings, blades
EI VMF	0,12—0,18	≤0,40	0,50—0,90	11.0—13,0	0,40—0,80	0,50—0,70	0,15—0,30	0,70—1,10	—	4,0	7,8	Rotor forgings, blades, fastenings
EI-747	0,14—0,19	0,17—0,37	0,40—0,70	11,0—13,0	0,50—0,80	0,8—1,0	0,25—0,30	—	—	6,0	9,0	Blades, forgings
EI-756	0,10—0,15	0,20—0,50	0,60—0,80	10,5—12,5	≤0,30	0,60—0,80	0,15—0,35	1,7—2,2	—	—	—	Rotor forgings, blades
EI-[illegible]	0,13—0,19	0,25—0,35	0,8—1,3	10,0—11,5	0,5—1,0	0,60—0,80	0,20—0,35	—	0,35—0,50	—	—	Forgings, blades
KH [illegible]	0,15—0,21	0,25—0,35	0,5—1,0	10,0—11,5	0,6—0,9	0,70—0,90	0,30—0,40	—	0,25—0,35	7,0	10,0	The same
EI MVFB	0,15—0,21	0,25—0,35	0,8—1,2	10,0—11,5	≤0,5	0,40—0,60	0,25—0,35	0,50—0,70	0,20—0,30	9,0	12,0	Forgings, blades
EI-993	0,15—0,22	0,25—0,50	0,25—0,50	11,0—13,0	≤0,35	0,40—0,60	0,20—0,35	0,40—0,60	0,30—0,50	—	—	Fastenings

Note: According to the calculated data boron is present only in the EI-993 steel in the amount of 0.003%.

TABLE 3

Metals Used in the SKR-100 Turbine With Steam Parameters of 300 atm abs and 650°C

Name of part		Brand	Remarks
Automatic shut-off-valve casting, steam and nozzle chests		EI-612	Forged
Inner cylinder		EI-612	Welded-forged
Outer cylinder		15XIMIFL	Cast
Rotor	First variant Second variant	EI-415 EI-726	With cooling
Blades		EI-612	
Diaphragm		EI-612	
Fastenings		EI-765	
Piping		EI-696P EP-17	

Metal Used in the Steam Turbine SKR-100

The manufacture of steam turbines with steam parameters of 300 atm abs and 650°C entails the use of austenitic steels, nickle-base alloys, and also pearlitic steels with cooling. At the present time the SKR-100 superimposed turbine with a power of 100 Mw is being manufactured with the above-mentioned steam parameters. Data concerning the metals used in the SKR-100 turbine are given in Table 3.

Obtaining large forgings of austenitic brands of steel presents the greatest difficulties.

At the present time the industry has assimilated the preparation of forgings of EI-612 steel (0.1C + 15Cr + 36Ni + 3W + 1.3Ti) from 3-4-metric-ton ingots, and of EI-726 steel (0.1C + 14Cr + 18Ni + 2.5W + + 1Nb + 0.02B) from 13-metric-ton ingots. From an ingot of EI-726 steel weighing 13 metric tons a forging of a 7,9000-kg official rotor

was prepared. The forging of the ingot was carried out between 1,120 and 800°C. The forging was subjected to heat treatment according to the following regime: double normalization at 1,150-1,160°C with air cooling and tempering at 740-760°C for 70 hours, furnace cooling to 100°C. An investigation of this rotor conducted at the Kharkov Turbogenerator Plant showed that the mechanical properties of specimens cut out from the top, bottom, and sides of the forging at 20° lay in the following ranges: $\sigma_T = 24 - 28.5$ kg/mm²; $\sigma_B = 54.5 - 57.5$ kg/mm²; $\delta = 32.7 - 42.2\%$; $\psi = 38 - 58\%$; $a_k = 8.45 - 24.8$ kg · m/cm². The stress-rupture strength for 100,000 hours at 630°C is 17 kg/cm². The plasticity at rupture is satisfactory. The fatigue limit at 20°C is $\sigma_{-1} = 17$ kg/cm². EI-726 brand steel is sufficiently stable with respect to structure and mechanical properties. After holding at 630° and 700°C for 5000 hours the impact strength was not less than 7-8 kg·m/cm².

In view of the fact that austenitic steels have a high coefficient of linear expansion and low thermal conductivity, the question of the starting regimes of the SKR-100 and similar turbines is one of primary importance. In order to decrease thermal stresses during the starting phases of the turbine, supplimentary heating of the flange joint is provided.

We should note that special urgency of a study of the oxidizing rate of steels at operating temperatures and a determination of the temperature threshold of the resistance of various brands of steel. The few studies dealing with this matter have shown that the oxidizing rate in air for austenitic steels at 650 and 750°C is expressed in thousandths and hundredths of a millimeter per year.

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